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DIVISION OF CHEMISTRY

Relation of the Occurrence of Cotton Root Rot to the Chemical Composition of Soils

AGRICULTURAL AND MECHANICAL COLLEGE OF TEXAS
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Soils in which cotton root rot generally occurs and causes much damage are high in fertility, as indicated by their content of nitrogen, phosphoric acid, and potash. They are also high in basicity, contain considerable quantities of lime, and are alkaline in reaction and heavy in texture. Soils on which cotton root rot rarely occurs are generally low in fertility, have a low basicity, are neutral to slightly acid in reaction, and are light in texture.

Alluvial, or river bottom, soils are usually high in fertility and basicity, but the disease does not generally occur on these soils. This indicates the action of inhibitory factors in alluvial soils not usually operative to the same degree in heavy upland soils.

The chemical composition of local areas of soil containing active root rot may be almost identical with that of adjacent soils on which root rot is not present. Chemical composition is simply one of a number of factors influencing the occurrence and virulence of the disease.

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RELATION OF THE OCCURRENCE OF COTTON ROOT ROT TO THE CHEMICAL COMPOSITION OF SOILS

G. S. Fraps, Chief, Division of Chemistry, and J. F. Fudge, Chemist

The plant disease commonly known as cotton root rot, caused by the fungus *Phymatotrichum omnivorum*, occurs over a very considerable part of the southwestern United States, having been found in Texas, New Mexico, Arizona, California, Arkansas, and Oklahoma. It has been found in about 200 counties of Texas (16), including practically all of the State except the Panhandle and parts of the mountainous country near the New Mexico line.

Cotton root rot affects not only cotton, but a large variety of other plants, including flowers, ornamental shrubs, trees, and weeds (17). It may persist for years on the roots of cotton and other plants which have not fully decayed (5, 10, 11, 16). Sclerotia, resting-bodies of the fungus, may be formed, remain dormant for years, and then become active centers of infection (9, 10, 12, 16). Spores are occasionally formed, but it has not yet been possible to cause them to infect plants (12, 16).

While cotton root rot is extensively distributed in Texas, the degree of damage caused by the disease varies in different parts of the State. In the eastern part of the State, where the soils are sandy and generally low in lime, the disease occurs only in limited areas and seldom causes much damage. In the black land areas near the center of the State where the soils are heavy in texture and calcareous, and in some other areas, the disease causes great damage. The damage done by root rot in the different sections of the State varies both with the soil and with the season. In East Texas there are some areas in which the disease occurs and causes damage, while in the black land section there are some areas in which the damage is usually low. The disease does not occur in the Panhandle of Texas, and causes only limited damage in West Texas in lands under irrigation, where at times there is some accumulation of soluble salts.

Taubenhaus, Ezekiel, and others (3, 16, 18) have shown that the root rot fungus grows much better and that the disease is more prevalent in a neutral or slightly alkaline soil than in an acid soil.

Ezekiel, Taubenhaus, and Fudge (4) found in laboratory studies that additions of calcium carbonate to acid soils caused greater increases in growth of the fungus than the same weights of calcium or potassium added in the form of nitrates, sulfates, or phosphates. It seems probable that there are other relations between the chemical and physical characteristics of soils and the degree of damage caused by root rot in them. The object of the work here presented was to ascertain whether such relations may exist. It was thought possible that the information secured might help in finding why the disease causes great damage in some soils and does not do so in others.

Analysis of Soils

The soil samples used in the study were selected by members of the Soil Survey as being typical of the respective soil types in the areas from which they were chosen. Total phosphoric acid, total potash, and nitrogen were determined by the methods already described (6). Active phosphoric acid and potash are the quantities in parts per million of soil which are soluble in 0.2 N nitric acid. The quantities of lime, magnesia, and acid-

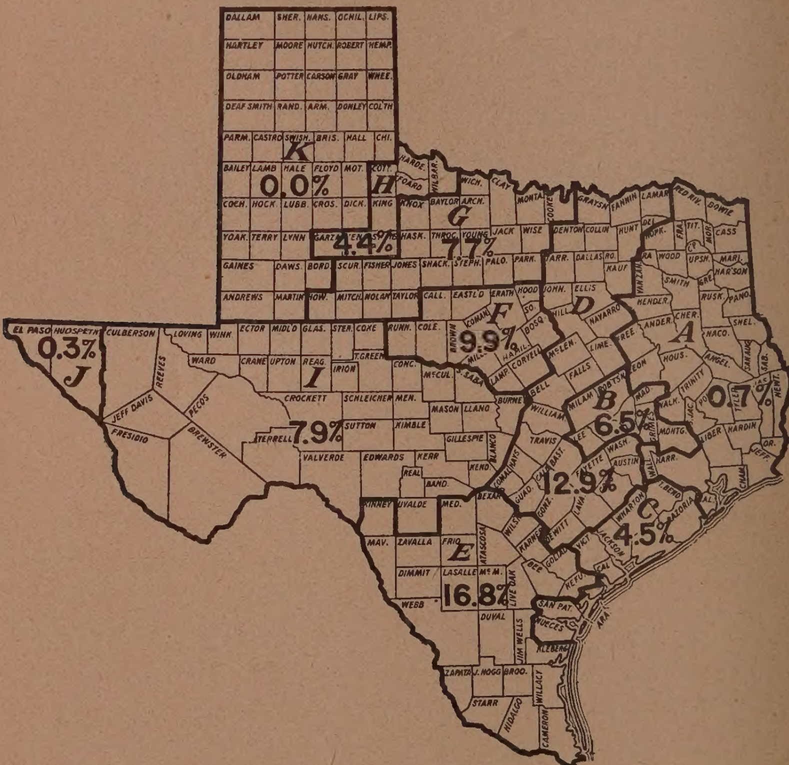

Fig. 1. Estimated losses from cotton root rot in 1928. The figures give the estimated reduction in yield of cotton.

soluble potash reported are those dissolved by digestion for 16 hours with hot hydrochloric acid of 1.115 specific gravity. Basicity, calculated as per cent calcium carbonate, represents the acid-consuming power of the soil (7), and was determined by treating the soil with an excess of acid and titrating the excess. The reaction (pH) of the soil was determined

either colorimetrically with a LaMotte Comparator or electrometrically with a quinhydrone electrode.

In arriving at the figures for the various constituents, as given in the several tables, the general modal value for a given soil type, rather than

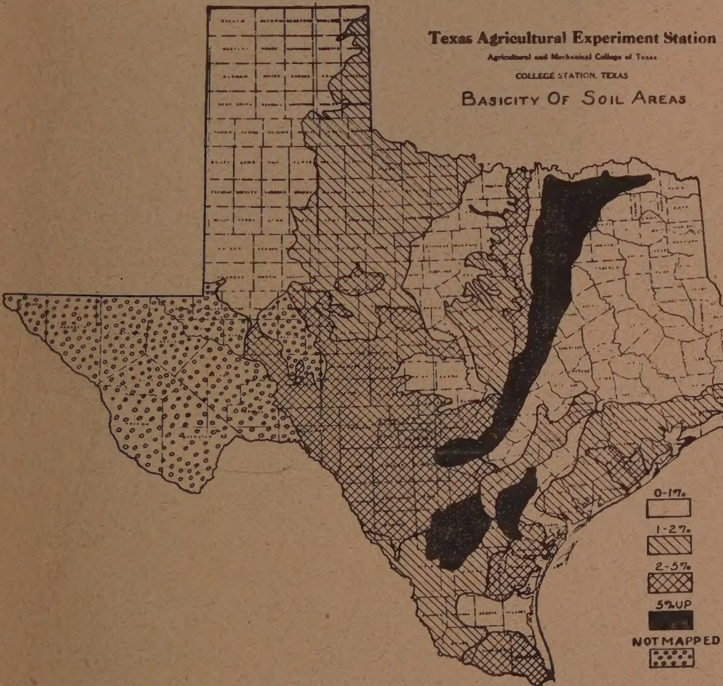

Fig. 2. Approximate basicity of Texas soil regions.

an arithmetical average, was used. Some individual samples may vary considerably from the values given. No attempt was made to weigh the values by number of samples, comparative area covered by the soil type, or proportion of the area devoted to the growth of crops which are susceptible to the root rot disease.

Comparative Composition of Soils from Areas in Which Root Rot Causes High and Low Degrees of Damage

The decrease in yield of cotton caused by root rot in different sections of the State, as mapped by Ezekiel and Taubenhaus (2), is shown in Fig. 1, and may be compared with the basicity of soil areas in Texas as mapped by Fraps and Carlyle (7), shown in Fig. 2, based upon the general soil map of Texas soils prepared by Carter (1). A fair relation between

the basicity of the soil and the occurrence of cotton root rot is apparent. The resemblance of the two maps might have been closer if the prevalence of the root rot had been mapped by soil areas instead of by counties as units, as was done in Fig. 1. A comparison of the two maps shows that the occurrence of cotton root rot is in general limited in soils with a

Soil Type	Phosphoric Acid		Nitrogen per cent	Potash			Lime per cent	Magnesia per cent	Basicity per cent	pH	No. of samples
	Total per cent	Active p.p.m.		Total per cent	Acid soluble per cent	Active p.p.m.					
High damage:											
Houston clay	.12	75	.16	1.00	.40	200	13.00	.60	20.00	7.6	28
Houston black clay	.08	100	.12	1.00	.40	350	4.00	.50	6.50	7.3	39
Houston clay loam	.03	150	.07	.65	.30	100	.70	.30	2.00	7.6	7
Houston loam	.03	30	.10	.80	.30	250	.50	.20	2.00	7.2	17
Low damage:											
Kirvin fine sandy loam	.04	15	.05	.55	.10	100	.21	.13	.40	7.0	16
Norfolk fine sandy loam	.03	25	.04	.45	.10	100	.11	.11	.27	6.7	16
Ruston fine sandy loam	.03	15	.03	.78	.09	95	.12	.12	.20	6.6	13
Tabor fine sandy loam	.04	6	.05	.60	.25	100	.23	.26	.45	6.8	15
Lufkin fine sandy loam	.04	20	.06	.75	.15	125	.23	.17	.40	6.5	22
High damage average	.05	89	.11	.86	.35	225	4.55	.40	7.12	7.4	91
Low damage average	.04	18	.05	.65	.14	104	.18	.14	.34	6.7	82

basicity of less than 1%, while it may be extensive in soils with a basicity of more than 2%. There are exceptions to this general relationship.

The sandy soils of East Texas may be taken in a general way to represent those in which there is little or no damage by cotton root rot, while the soils of the Houston series of the black land area may be taken to represent those in which the damage is high. Table 1 contains a comparison of the chemical composition of some soils of the Houston series, representing the areas in which a high degree of damage is caused by root rot, and of the Norfolk, Kirvin, Ruston, Tabor, and Lufkin series, representing the areas in which very little damage is caused by the disease. On an average, the soils in which root rot causes great damage are higher in total phosphoric acid, active phosphoric acid, total nitrogen, total potash, acid soluble potash, active potash, lime, and magnesia than are the soils in which the occurrence of root rot is very limited. The soils which are favorable to root rot are also high in basicity and tend to be slightly alkaline in reaction, while the soils which are unfavorable are neutral or slightly acid in reaction. The favorable soils are heavy soils, while most of the unfavorable soils are more porous and open.

The soils selected for the comparison given are extreme cases. The differences found may have no connection with the degree of damage caused by the disease.

Composition of Soils in Four Areas as Related to Cotton Crop Losses Caused by Root Rot

The various areas outlined by Ezekiel and Taubenhaus (2), based upon reductions in yield of cotton caused by root rot, were taken as a basis for further study. In Table 2 is given the average chemical composition of representative samples of the principal soil types for the four regions in which most of the cotton grown in Texas is produced. As noted above, these are averages of modal values for the individual soil types, not weighed in any way.

The estimated reduction in yield of cotton averaged 6.5% or less in areas A and C (Table 2) comprising in general the East Texas Timber Country and the Gulf Coast Prairies. Most of the soils of these areas

Table 1. Comparative composition of surface soils from areas in which root rot causes high and low degrees of damage

Table 2. Approximate average composition of surface soils of principal soil types of areas of varying cotton crop losses caused by root rot

Designation of Area in Figure 1	Approximate soil area	Reduction in yield of cotton per cent	Phosphoric Acid		Nitrogen per cent	Potash			Lime per cent	Magnesia per cent	Basicity per cent	pH
			Total per cent	Active ppm.		Total per cent	Acid soluble per cent	Active ppm.				
A	East Texas Timber Country........	0.7	.033	15	.050	.71	.14	110	.10	.17	.35	6.5
C	Gulf Coast Prairie...	4.5	.032	38	.078	.78	.17	184	.39	.24	.71	6.5
D	Blackland Prairies..	12.9	.052	56	.099	.76	.28	207	1.97	.45	3.47	7.0
E	Rio Grande Plain...	16.8	.061	53	.091	1.34	.70	456	0.61	.45	1.34	7.4

are light soils, and principally fine sandy loams. The Lake Charles soils are the only heavy soils occupying a considerable acreage. Most of the cotton crop losses, however, occurred on the occasional heavy soils of the areas. The soils are deficient or low in nitrogen, phosphoric acid, potash, lime, magnesia, and basicity, and, as a rule, are slightly acid.

The average cotton crop loss was quite high (12.9% and 16.8%) on the soils of the Blackland Prairies and the Rio Grande Plain. These soils are relatively quite high in phosphoric acid, nitrogen, potash, and basicity, contain considerable limestone, and are heavy in texture and alkaline in reaction.

The results in general indicate that crops grown in the more fertile soils are damaged much more by the cotton root rot than are those grown in the less fertile soils.

The results here reported are not in conflict with the conclusions of

Table 3. Relation of chemical composition of soil types to the degree of damage caused by cotton root rot. Upland surface soils

Area and Type	Phosphoric Acid		Nitrogen per cent	Potash			Lime per cent	Magnesia per cent	Basicity per cent	pH	No. of Samples
	Total per cent	Active ppm.		Total per cent	Acid soluble per cent	Active ppm.					
Blackland Prairies-High damage:											
Bell clay	.08	150	.12	1.10	.45	300	2.40	.90	4.00	7.3	19
Crockett fine sandy loam	.03	40	.05	.75	.11	150	.25	.25	.75	6.4	8
Crockett loam	.04	30	.09	.62	.20	300	.24	.16	1.00	6.4	3
Crockett clay loam	.03	10	.10	.60	.12	175	.35	.25	.50	6.2	6
Crockett clay	.06	8	.14	.75	.40	275	.60	.90	1.60	7.3	2
Houston clay loam	.03	150	.07	.65	.30	100	.70	.30	2.00	7.6	7
Houston loam	.03	30	.10	.80	.30	250	.50	.20	2.00	7.2	17
Houston clay	.12	75	.16	1.00	.40	200	13.00	.60	20.00	7.6	28
Houston black clay	.08	100	.12	1.00	.40	350	4.00	.50	6.50	7.3	39
Blackland Prairie-Low damage:											
Wilson clay loam	.04	25	.08	.80	.25	150	.55	.35	1.00	7.0	17
Wilson fine sandy loam	.03	25	.07	.60	.13	85	.30	.15	0.50	6.4	10
Wilson clay	.05	20	.08	.60	.25	150	.80	.40	1.75	7.0	13
Gulf Coast Prairie-High damage:											
Victoria fine sandy loam	.04	100	.06	2.00	.25	500	.50	.30	.75	7.8	12
Lake Charles clay	.04	20	.12	.70	.30	125	.55	.30	1.25	5.8	26
Gulf Coast Prairie-Medium damage:											
Lake Charles clay loam	.03	20	.08	.28	.08	65	.40	.30	.80	6.6	7
Gulf Coast Prairie-Low damage:											
Lake Charles fine sandy loam	.02	10	.05	.16	.05	47	.12	.08	.05	5.9	1
East Texas Timber Country-Low damage:											
Bastrop fine sandy loam	.03	20	.04	1.00	.25	100	.30	.20	1.00	7.2	8
Kirvin fine sandy loam	.04	15	.05	.55	.10	100	.21	.13	.40	7.0	16
Lufkin fine sandy loam	.04	20	.06	.75	.15	125	.23	.17	.40	6.5	22
Lufkin clay loam	.02	10	.07	.64	.12	90	.30	.15	.25	6.0	5
Tabor fine sandy loam	.04	6	.05	.60	.25	100	.23	.26	.45	6.8	15
Ruston fine sandy loam	.03	15	.03	.78	.09	95	.12	.12	.20	6.6	13
East Texas Timber Country-No damage:											
Norfolk fine sand	.03	25	.04	.70	.09	90	.12	.09	.20	6.5	43
Norfolk fine sandy loam	.03	25	.04	.45	.10	100	.11	.11	.27	6.7	16
Susequehanna clay	.05	10	.08	.90	.15	150	.30	.22	.....	5.6	5
Susequehanna clay loam	.02	10	.05	.80	.13	140	.19	.31	.42	6.2	3
Susquehanna fine sandy loam	.03	15	.05	.65	.14	125	.13	.11	.30	6.2	43
Rio Grande Plain-High damage:											
Hidalgo fine sandy loam	.05	85	.07	1.15	.58	573	.99	.34	1.18	7.7	2
Victoria fine sandy loam	.06	100	.07	1.80	.32	500	.45	.30	1.00	7.6	12
Rio Grande Plain-Medium damage:											
Duval fine sandy loam	.03	20	.06	1.00	.30	200	.30	.20	.30	6.6	12
Victoria clay loam	.16	*500	.15	1.75	.90	600	.90	.60	1.60	7.4	4
Victoria clay	.04	25	.13	1.00	.60	400	.85	.70	3.50	7.3	11
Webb fine sandy loam	.05	25	.06	1.20	.42	350	.40	.40	.80	7.5	11
Rio Grande Plain-Low damage:											
Brennan fine sandy loam	.04	63	.10	1.50	.80	*550	.50	.61	1.00	.....	3
Edwards Plateau and Rolling Plains-Medium damage:											
Abilene clay loam	.06	25	.16	1.25	.60	500	1.00	.60	1.05	7.2	11
Edwards Plateau and Rolling Plains-Low damage:											
Miles fine sandy loam	.04	40	.05	1.20	.25	200	.30	.22	.50	7.1	15
Denton clay	.07	25	.15	1.00	.45	150	.....	.60	5.00	7.3	14

*Excluded from averages.

Table 4. Relation of chemical composition of soil types to the degree of damage caused by cotton root rot. Upland subsoils

	Phosphoric Acid			Potash							
	Total per cent	Active ppm.	Nitrogen per cent	Total per cent	Acid soluble per cent	Active ppm.	Lime per cent	Magnesia per cent	Basicity per cent	pH	No. of Samples
Blackland Prairies-High damage:											
Bell clay	.07	70	.07	1.00	.50	200	2.50	.60	5.00	7.4	15
Crockett fine sandy loam	.03	15	.06	.75	.30	150	.60	.40	1.25	7.0	9
Crockett loam	.04	45	.05	.65	.45	150	1.20	.80	2.50	7.0	4
Crockett clay loam	.04	10	.07	.85	.40	150	.50	.45	.70	6.3	5
Houston loam	.03	12	.06	.80	.27	50	.45	.30	1.10	6.5	8
Houston clay loam	.03	10	.06	.75	.50	150	2.25	.45	4.50	7.6	7
Houston clay	.10	10	.08	1.00	.35	65	20.00	.60	10.00	7.5	23
Houston black clay	.08	35	.08	.80	.40	150	5.00	.60	5.00	7.3	30
Blackland Prairies-Low damage:											
Wilson fine sandy loam	.03	15	.06	.65	.25	125	.40	.40	.95	6.6	10
Wilson clay loam	.04	15	.07	.08	.25	125	.55	.40	1.25	7.0	17
Wilson clay	.04	12	.06	.09	.25	125	1.00	.40	1.50	6.8	13
Gulf Coast Prairies-High damage:											
Victoria fine sandy loam	.05	100	.06	1.60	.40	275	.45	.35	1.00	7.6	12
Lake Charles clay	.03	10	.07	.60	.35	150	.60	.50	1.25	6.5	32
Gulf Coast Prairie-Medium damage:											
Lake Charles clay loam	.02	15	.04	.25	.12	50	.50	.40	1.00	7.2	10
Gulf Coast Prairies-Low damage:											
Lake Charles fine sandy loam	.02	9	.04	.20	.07	58	.13	.12	.20	5.9	2
East Texas Timber Country-Low damage:											
Bastrop fine sandy loam	.04	10	.05	1.10	.50	200	.50	.40	.60	6.8	8
Kirvin fine sandy loam	.06	10	.05	.65	.30	100	.25	.25	.60	6.4	18
Lufkin fine sandy loam	.03	10	.05	.80	.24	100	.40	.32	.80	6.5	20
Lufkin clay loam	.02	13	.04	.55	.20	85	.35	.25	.60	6.0	7
Tabor fine sandy loam	.04	7	.04	.60	.25	100	.28	.27	.55	6.8	15
East Texas Timber Country-No damage:											
Norfolk fine sand	.02	15	.02	.70	.09	75	.11	.10	.12	6.3	41
Norfolk fine sandy loam	.03	10	.04	.80	.15	100	.14	.12	.25	6.2	18
Susquehanna clay	.06	5	.05	.75	.40	250	.25	.48	.55	5.9	5
Susquehanna clay loam	.03	8	.04	1.30	.18	125	.20	.20	.34	5.8	6
Susquehanna fine sandy loam	.03	9	.04	.88	.24	125	.20	.28	.53	6.0	41
Rio Grande Plain-High damage:											
Hidalgo fine sandy loam	.05	100	.06	1.40	.59	435	3.52	.73	5.95	7.8	2
Victoria fine sandy loam	.049	100	.05	1.60	.40	350	.53	.30	2.00	7.8	12
Rio Grande Plain-Medium damage:											
Duval fine sandy loam	.041	10	.05	1.10	.30	200	.20	.27	.34	7.0	9
Victoria clay	.03	135	.11	1.40	.65	250	.87	1.00	3.80	.....	9
Victoria clay loam	.12	650	.06	2.00	.75	400	2.80	.78	7.80	7.5	5
Rio Grande Plain-Low damage:											
Brennan fine sandy loam	.03	40	.05	1.80	.57	500	.28	.47	.59	7.5	4
Edwards Plateau and Rolling Plains-Medium damage:											
Abilene clay loam	.06	30	.09	1.25	.65	300	4.00	.60	4.50	7.5	19
Edwards Plateau and Rolling Plains-Low damage:											
Denton clay	.06	10	.08	1.00	.50	100	.65	.70	10.00	7.6	16
Miles fine sandy loam	.04	15	.05	1.40	.50	250	.40	.40	.65	7.3	21

Jordan et al. (8) that the use of suitable fertilizers, by acceleration of maturity, may be a means of evading losses due to progressive killing of cotton plants by root rot on heavily infected fields, or that the increases in total yield by means of the fertilizers may more than compensate for losses that would otherwise occur. The work here reported shows that root rot is more destructive on the fertile soils than in the poor soils, while the work of Jordan shows that the use of fertilizers may result in producing a larger crop of cotton before the plant is killed by the disease.

Relation of Composition of Soil Type to the Degree of Damage Caused by Cotton Root Rot

As already stated, within the same area there are great differences in the damage caused by cotton root rot on different soil types. On some soil types crop losses may be very great, while on other soil types the damage is comparatively light. It is somewhat difficult to classify some of the soil types with respect to the damage caused by root rot, since there is a variation in the damage caused by the disease in different years.

Information regarding the relative damage caused by root rot on various soil types within the same general area have been collected from extensive field observations by Dr. J. J. Taubenhaus of the Division of Plant Pathology and Physiology and Mr. W. T. Carter of the Division of Soil Survey. They classified the soil types according to whether the disease caused high, medium, low, or no damage to susceptible plants grown on the soils.

The average chemical composition of surface soils (mostly 0-7″ in depth) of these individual types is given in Table 3. Similar analyses for the subsoils (mostly 7″-19″) are given in Table 4. In these tables, the soil types are grouped first by the general soil region in which they occur, and then by the degree of damage caused by cotton root rot on the type as a whole. Only upland soils are given, for reasons which will be discussed later. The analyses used are those of typical soils collected by the field agents of the Bureau of Chemistry and Soils in connection with their surveys of various counties in Texas.

In considering the data presented, it must be remembered that individual samples of a given soil type may differ considerably in composition; the figures given are those which are considered as approximate modal values. In the case of most soil types, there may be exceptional local areas not conforming to the estimate for damage or the values given for chemical composition. For example, on some areas of the Wilson clay loam, there is either no damage or it is very small. However, other areas of Wilson clay loam are known in which the loss in a given year has been as high as 60 per cent. Individual variations in composition may be responsible for part of this variation. The areas of Wilson soils on which high damage occurs are calcareous and have an alkaline reaction, while Wilson soils on which little damage by root rot occurs are non-calcareous and have a slightly acid reaction.

Table 5. Relation between average chemical composition of soil types and degree of damage caused by cotton root rot

	High Damage	Medium Damage	Low Damage	No Damage
Total Phosphoric acid, per cent:				
Blackland Prairies	.055		.045	
Gulf Coast Prairie	.040	.030	.020	
East Texas Timber Country			.033	.032
Rio Grande Plain	.055	.070	.040	
Edwards Plateau		.060	.055	
Average of all types	.053	.060	.039	.032
Alluvial			.120	.112
Active Phosphoric acid, parts per million:				
Blackland Prairies	66		23	
Gulf Coast Prairie	60	20	10	
East Texas Timber Country			14	17
Rio Grande Plain	143	25	63	
Edwards Plateau		25	32	
Average of all types	77	24	23	17
Alluvial			150	240
Nitrogen, per cent:				
Blackland Prairies	.106		.083	
Gulf Coast Prairie	.090	.080	.050	
East Texas Timber Country			.050	.052
Rio Grande Plain	.070	.100	.100	
Edwards Plateau		.160	.100	
Average of all types	.098	.108	.069	.052
Alluvial			.13	.10
Total Potash, Per cent:				
Blackland Prairies	.82		.67	
Gulf Coast Prairie	1.35	.28	.16	
East Texas Timber Country			.74	.70
Rio Grande Plain	1.48	1.24	1.50	
Edwards Plateau		1.25	1.10	
Average of all types	1.00	1.07	.79	.70
Alluvial			1.75	2.00
Acid Soluble Potash, per cent:				
Blackland Prairies	.30		.21	
Gulf Coast Prairies	.28	.08	.05	
East Texas Timber Country			.16	.12
Rio Grande Plain	.45	.55	.80	
Edwards Plateau		.60	.35	
Average of all types	.32	.48	.41	.12
Alluvial			.75	.77
Active Potash, parts per million:				
Blackland Prairies	233		130	
Gulf Coast Prairie	312	65	47	
East Texas Timber Country			101	121
Rio Grande Plain	535	392		
Edwards Plateau		500	175	
Average of all types	292	355	116	121
Alluvial			300	385
Lime, per cent:				
Blackland Prairies	2.44		.55	
Gulf Coast Prairie	.53	.40	.12	
East Texas Timber Country			.23	.17
Rio Grande Plain	.72	.61	.50	
Edwards Plateau		1.00	.30	
Average of all types	1.89	.64	.33	.17
Alluvial			2.91	2.87
Magnesia, per cent:				
Blackland Prairies	.45		.30	
Gulf Coast Prairie	.30	.30	.08	
East Texas Timber Country			.17	.17
Rio Grande Plain	.32	.48	.61	
Edwards Plateau		.60	.41	
Average of all types	.41	.47	.26	.17
Alluvial			.65	.55

Table 5. Relation between average chemical composition of soil types and degree of damage caused by cotton root rot (Continued)

	High Damage	Medium Damage	Low Damage	No Damage
Basicity, per cent:				
Blackland Prairies	4.26	....	1.08	....
Gulf Coast Prairie	1.00	.80	.05	....
East Texas Timber Country	....	....	.45	.24
Rio Grande Plain	1.09	1.55	1.00	....
Edwards Plateau	....	1.05	2.75	....
Average of all types	3.26	1.34	0.96	.24
Alluvial	....	....	7.20	3.35
pH:				
Blackland Prairies	7.0	....	6.8	....
Gulf Coast Prairie	6.8	6.6	5.9	....
East Texas Timber Country	....	....	6.7	6.2
Rio Grande Plain	7.6	7.2	....	....
Edwards Plateau	....	7.2	7.2	....
Average of all types	7.1	7.0	6.7	6.2
Alluvial	....	....	7.2	7.4

The analyses presented in Table 3 were averaged by areas and the results are presented in Table 5. The analyses for the soil types, as grouped in Table 3 with respect to degree of damage, were also averaged regardless of the area in which they occur, and these averages are given as "Average of all types." Values for active phosphoric acid in the Victoria fine sandy loam and active potash in the Brennan fine sandy loam were omitted from the averages in Table 5, because they were very much out of line with the other soil types in the same groups and for the further reason that, as noted in the last column of Table 3, the number of samples of these two types was quite small (4 and 2) and their inclusion would have resulted in an incorrect weighted average. Averages for alluvial soils (see also Table 7) are given in Table 5, but are not included in the averages of the upland soil types.

The final averages for each constituent were calculated to relative values with 100 as the quantity of the constituent in soil in which damage was high. These results are given in Table 6.

Table 6. Relative average composition of soils on which cotton root rot caused different degrees of damage

	High Damage	Medium Damage	Low Damage	No Damage
Total phosphoric acid	100	113	73	60
Active phosphoric acid	100	31	30	22
Nitrogen	100	110	71	53
Total potash	100	107	79	70
Acid-soluble potash	100	153	128	53
Active potash	100	122	40	41
Lime	100	34	17	9
Magnesia	100	115	63	41
Basicity	100	41	29	8
Reciprocal of H-ion concentration	100	80	44	14
Average	100	91	57	36

The data for subsoils are given in Table 4, but they were not summarized and averaged, since they show essentially the same trends as do the data for the surface soils which are presented in Tables 5 and 6.

In the following discussion of the data presented in Tables 3 to 6 each element is considered separately.

Phosphoric acid. Total phosphoric acid in groups of soil types on which the high damage by root rot occurred was about two-thirds greater than that in the low and no damage groups. Active phosphoric acid was about three times as great in the high damage group as in the medium damage and low damage groups, and five times as great as in the group with no damage.

Nitrogen. Nitrogen in the high damage group was about one-half higher than that in the low damage group, and twice as high as that in the group without damage.

Potash. Total potash was about one-half greater in the high damage group than in the no damage group, and one-fourth higher than in the low damage group. Acid-soluble potash showed considerable variation in the high, medium, and low damage groups, but the quantity in the high damage group was about twice that in the group on which the disease caused no damage. Active potash in the high damage group was approximately three times that in the low damage and no damage groups.

Lime and Basicity. Lime content and basicity are intimately associated in soils, since the major part of the basicity of highly basic soils is due to the presence of calcium carbonate in the soil. Differences in lime content and basicity were greater than those secured with any other chemical constituent. Lime and basicity were ten or twelve times greater in the high damage group than in the no damage group, and several times greater than in the medium damage and low damage groups.

pH. The pH of the different groups does not vary greatly; all groups have pH values very close to the neutral point (pH 7.0). The pH is a logarithmic value related to hydrogen ion concentration. When the hydrogen ion concentrations corresponding to the pH values are used, differences in the several groups become apparent. The hydrogen ion concentrations in the low and no damage groups are considerably higher than those in the high and medium groups. In the calculation of the relative concentrations (Table 6), the reciprocal of the hydrogen ion concentration was used, in order to keep the value of the high root rot group at 100, as in the other determinations. The relative value of the reciprocal in the high damage group is about five times that in the no damage group.

Summary. The data can perhaps best be summarized by the statement that, in general, soils in which a high degree of damage is caused by root rot are those in which active phosphoric acid, active potash, lime, basicity, and pH are high. Of these, perhaps the most important are high lime and high basicity, calcareous soils in almost all cases providing an excellent environment for the rapid development of the disease.

Composition of Some Alluvial Soils

Only upland soil types have so far been discussed. Alluvial soils are soils laid down in the river bottoms, subject to occasional or frequent overflow with consequent deposition of soil material from all of the soil areas through which the streams pass, and form a special group of soils

Table 7. Average composition of some important alluvial soil types

Soil Type	Phosphoric Acid		Nitrogen	Potash			Lime	Magnesia	Basicity	pH	No. of Samples
	Total per cent	Active ppm.	per cent	Total per cent	Acid soluble per cent	Active ppm.	per cent	per cent	per cent		
Surface Soils:											
Ochlockonee clay	.085	70	.140	.80	.33	270	.90	.45	1.70	6.8	6
Ocklockonee silty clay loam	.060	34	.055	1.35	.25	125	.74	.48	.35	5.8	6
Ocklockonee fine sandy loam	.045	30	.060	.90	.10	130	.18	.14	.50	6.6	99
Trinity clay	.125	50	.150	1.25	.60	250	3.00	.75	5.00	7.3	42
Frio clay	.150	155	.150	1.35	.80	330	7.50	.85	15.00	7.3	12
Catalpa clay	.130	35	.120	1.25	.63	275	4.00	.60	10.00	7.3	16
Frio fine sandy loam	.060	130	.070	1.10	.30	250	.50	.20	.85	7.3	11
Frio loam	.085	200	.110	1.50	.50	430	5.00	.55	9.50	7.4	11
Miller fine sandy loam	.070	200	.060	1.60	.30	250	.30	.25	.60	7.3	10
Miller clay	.125	125	.100	2.00	.85	300	5.00	1.00	10.00	7.3	11
Pledger clay	.070	250	.080	2.30	1.20	250	3.00	2.50	5.00	7.5	3
Subsoils:											
Ocklockonee clay	.045	25	.080	.75	.30	175	.70	.43	1.30	6.8	7
Ocklockonee silty clay loam	.060	34	.055	1.35	.25	125	.24	.48	.35	5.8	6
Ocklockonee fine sandy loam	.040	15	.045	1.00	.10	80	.20	.15	.45	6.0	9
Trinity clay	.125	100	.150	1.25	.55	250	3.00	.75	5.00	7.3	42
Catalpa	.115	35	.125	1.25	.55	250	8.00	.75	15.00	7.4	17
Frio clay	.125	35	.095	1.20	.75	150	6.50	.75	12.00	7.5	12
Frio fine sandy loam	.045	58	.050	1.25	.42	200	1.00	.30	2.00	7.4	16
Frio loam	.058	47	.065	0.95	.32	290	5.40	.65	9.50	7.6	12
Miller fine sandy loam	.050	50	.045	1.50	.47	200	2.50	.40	5.00	7.7	10
Miller clay	.100	100	.070	2.00	.85	200	5.00	1.00	10.00	7.5	12
Pledger clay	.070	250	.080	2.30	1.20	250	3.00	2.50	5.00	7.5	3

with respect to damage by cotton root rot. In general, the damage caused by root rot on alluvial soils is low, although occasional areas occur in which considerable damage is done. The disease has been artificially introduced into a typical river bottom soil (19) and reappeared on the cotton crop of the following year. This indicates that environmental factors other than the nature and composition of the alluvial soils may prevent infestation of the soil or inhibit the growth of the organism. Rea (13) found the sclerotial resting stage of the fungus in alluvial soils as well as in upland soils. The average composition of a number of important alluvial soil types is given in Table 7. In general, the soils are considerably more fertile than the general average of the soils of the various soil regions in which they occur. Lime, basicity, and pH are all considerably higher. In so far as the chemical composition of the alluvial soils is concerned, then, the disease would be expected to do a great deal of damage on these soils. The fact that it does not do so

must be attributed to factors other than the chemical composition of the soils here discussed.

The Composition of Adjacent Soils of Same Type Bearing Diseased and Disease-free Cotton Plants

Cotton root rot has a tendency to infect plants in irregular spots surrounding the center of infection. These spots vary considerably in size. The areas on which plants are not infected may be favorable to the disease, but the disease may not have progressed far enough to have reached them. The physical and chemical differences between adjacent areas on which the plants are diseased or healthy may be insignificant. In spite of this fact, it was considered desirable to make some analyses of samples of paired soils from spots bearing diseased and disease-free plants. The samples were collected by Dr. J. J. Taubenhaus of the Division of Plant Pathology and Physiology. Samples of soil from areas on which plants were infected or uninfected were analyzed. The results are given in Table 8. Many of the differences between the samples from the two areas are well within the range of error of the analytical determination. The reactions (pH) of the root-rot-free areas of the Crockett fine sandy loam and clay loam and the Wilson fine sandy loam were slightly lower than those for the infected areas, and may account in part for the absence of the disease in the uninfected areas. However, they are so nearly neutral that the slight increase in acidity of the uninfected area could probably have had comparatively little influence on the control of the disease (3, 16). This is emphasized by the fact that in the Wilson clay loam, the most acid soil studied, there was practically no difference in pH between the area carrying the infected plants and that carrying uninfected

Table 8. Comparison of composition of adjacent samples of the same type bearing diseased (R) and disease-free (F) cotton plants of the same type

	Depth	Phosphoric Acid				Nitrogen		Potash				Basicity		pH	
		Total		Active				Total		Active					
	inches	R per cent	F per cent	R ppm	F ppm	R per cent	F per cent	R per cent	F per cent	R ppm	F ppm	R per cent	F per cent	R	F
Crockett fine sandy loam	0–7	.035	.037	12	13	.062	.082	.41	.37	120	103	.27	.27	6.8	6.1
	7–14	.037	.043	6	6	.067	.083	.34	.37	55	49	.25	.28	6.9	5.9
	14–24	.044	.043	5	6	.088	.092	.51	.56	91	101	.55	.30	6.1	5.5
Crockett clay loam	0–7	.052	.051	11	17	.148	.111	.61	.81	175	130	1.22	.82	6.1	5.9
	7–19	.058	.035	7	7	.087	.069	.80	.72	107	99	1.89	1.34	7.3	5.9
Lufkin fine sandy loam	0–7	.040	.043	102	98	.061	.061	.90	.88	235	280	1.14	.33	7.4	7.1
	7–19	.016	.013	13	15	.084	.084	.86	.64	147	357	1.36	1.10	7.2	6.4
Wilson fine sandy loam	0–7	.034	.035	25	34	.132	.123	1.16	1.18	136	112	.38	.30	6.9	6.4
	7–16	.019	.021	9	9	.050	.053	1.22	1.19	58	51	.14	.18	7.1	6.5
	16–24	.020	.019	5	6	.093	.083	.96	1.01	107	81	.78	.83	6.7	6.8
Wilson clay loam	0–7	.049	....	8	11	.136	.146	.30	.33	105	105	.90	1.00	5.8	5.6
	7–19	.048	.041	9	6	.114	.079	.34	.31	101	80	1.18	1.17	5.8	5.9
Wilson clay	0–7	.042	.027	86	14	.052	.052	.74	.92	244	131	1.16	1.18	7.2	6.7
	7–19	.047	.024	21	15	.049	.049	.67	.67	142	100	1.01	1.41	6.9	6.7

plants. The active potash in the soil of the infected area of the Wilson clay is slightly higher than that in the root-rot-free area, but on the other hand that of the root-rot-free area of the Lufkin fine sandy loam is considerably higher than that of the infected area, while there is no significant difference between the two areas with the other soil types. No other significant difference occurred.

The data given in Table 8 emphasize the fact that the chemical composition of the soil is only one of a number of factors which determine the occurrence and virulence of the cotton root disease. It should be repeated in this connection that discussion of the relation of chemical composition of the soil to the damage caused by root rot, as given in this bulletin, is based upon general, broad relationships and is not applicable to particular local areas, in which local factors other than the chemical composition of the soil may determine whether or not the disease causes serious damage at any particular time.

General Discussion

The preceding work shows that in general a soil which contains appreciable amounts of lime and is slightly alkaline, of good fertility, and a loam or clay in texture is, in general, favorable to root rot. On the other hand, a soil which is low in lime, slightly acid or acid, and sandy in character, is unfavorable to the disease.

The extent and rapidity with which the cotton root rot fungus spreads, its virulence (or the rapidity with which it grows and kills the plant), and its persistence (or ability to continue over from one season to another), all vary in different soils and during different seasons. Of the various factors concerned with differences in the growth of the fungus due to soil differences, the most important appear to be the pH and basicity as has already been pointed out (3, 4, 16). Much work has been done on the relation of the organism to the acidity of the soil (3, 4, 16), and some of the results obtained indicate that the presence of sufficient quantities of lime are of more importance to the favorable growth of the organism than are large quantities of nitrogen, phosphoric acid, or potash (4).

Variations in the relative damage to plants caused by differences in soil fertility may perhaps be associated with variations in the chemical composition of the roots of the plants. Since the root rot fungus feeds upon the roots, the roots of plants which have been grown in some soils may be slightly more favorable to the growth of the fungus than they are when grown in other soils. This is a matter that requires further investigation. Ezekiel, Taubenhaus, and Fudge (5) have shown that extracts from the roots of monocotyledonous plants (which are not affected by cotton root rot) contain substances which inhibit the growth of root rot and which are apparently absent in extracts from susceptible dicotyledonous plants.

The greater persistence of the cotton root rot in some soils than in others may be due to several causes. Sclerotia may be produced in

greater numbers in some soils than in others. Some soils, by obstruction of the access of air to the sclerotia or otherwise, may delay germination for years, thereby causing the disease to persist for a longer time than in others. The moisture-holding capacity of heavy soils is much greater than that of light soils. The moisture may be more favorable to the growth of the organisms (20) in some soils than in others. The obstruction of air may hinder the decay of roots, so that they continue to be a suitable medium for the food of the organism for a longer period in some soils than in others. The weeds which serve as hosts may live better in some soils than in others. These considerations lead to the conclusion that a favorable root medium may favor the formation of sclerotia, while the physical character of the soil may be a factor in preserving the roots, the sclerotia, or the fungus over the winter or for a longer period.

SUMMARY

Soils of the Houston series, typical of the Blackland prairies, on which root rot causes a high degree of damage, are higher in total phosphoric acid, active phosphoric acid, total nitrogen, total potash, acid-soluble potash, active potash, lime, and magnesia, than are the fine sandy loams of the Norfolk, Kirvin, Ruston, Tabor, and Lufkin series, typical of the East Texas Timber Country, on which root rot is very limited. The Houston soils are also high in basicity and tend to be slightly alkaline in reaction (pH), while those on which root rot is of slight occurrence are of low basicity and are neutral to slightly acid.

Soils of the East Texas Timber Country and the Gulf Coast Prairies, on which losses of cotton due to root rot were low, are mostly light in texture, deficient or low in phosphoric acid, nitrogen, potash, lime, and magnesia, low in basicity, and slightly acid in reaction. Soils of the Blackland Prairies and Rio Grande Plains, on which losses of cotton due to root rot were high, are chiefly heavy in texture and high in fertility, as indicated by the content of phosphoric acid, nitrogen, and potash. They also have a high basicity, contain considerable limestone, and are alkaline in reaction.

The principal soil types of Texas were grouped according to the degree of damage caused by cotton root rot. On an average, soils on which no damage was caused by the disease contained only about two-thirds as much total phosphoric acid, one-half as much nitrogen, total potash, and magnesia, one-third as much acid soluble potash, one-fifth as much active phosphoric acid and active potash, one-seventh as much lime and basicity, and seven times as great a concentration of hydrogen ions in the soil suspension, as did soils on which damage was high. The average composition of soils on which medium and low degrees of damage were caused by the disease was, in general, intermediate between that of the soils in the high damage and no damage groups, although several exceptions occur.

Alluvial soils, or soils of river bottoms, were relatively quite high in fertility and basicity. The low damage on these soils must be due to other factors which counteract the high fertility and basicity.

The chemical compositions of adjacent areas of a number of types, one area of which contained active root rot while the other was free of the disease, were practically identical, with the possible exception of pH, indicating that chemical composition is only one of many factors influencing the occurrence and virulence of the root rot disease.

There is a possibility that chemical composition of the soil may slightly affect the composition of the roots of the cotton plant so that plants grown on limestone soils are more susceptible to cotton root rot than are those grown on non-calcareous sandy soils. The physical or chemical characteristics of the soil may affect the production of sclerotia, their period of germination, the decay of roots in which the fungus may survive, and other conditions which affect the over-wintering of the root rot fungus, so that clay or loamy limestone soils are more favorable to the carry-over of the disease than are slightly acid sandy soils.

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